Stoch Environ Res Risk Assess (2009) 23:341–347
DOI 10.1007/s00477-008-0219-5

ORIGINAL ARTICLE

Assessment of heavy metal contamination of roadside soils in Southwest China

Junhong Bai · Baoshan Cui · Qinggai Wang · Haifeng Gao · Qiuyi Ding

Published online: 16 February 2008

Abstract Topsoil (0–20 cm) samples were collected from the edge of roads to the locations about 200 m off the roads along the four roads with different transportation periods in October 2005. Total concentrations of As, Cd, Cr, Cu, Ni, Pb and Zn were determined using the inductively coupled plasma atomic absorption spectrometry in order to assess and compare road transportation pollution. Results showed that with the exception of As, Cu and Pb, the average concentrations of heavy metals were generally, higher than the regional elemental background values. Most soil samples were moderately or highly polluted by Cd or Ni, but the contamination index (P_i) values for As, Pb and Zn were lower than other heavy metals in all sites. Among the four roads, heavy metal pollution was heavier for Dali Road due to longer transportation periods, while low or no contamination could be observed for the other roads. However, the integrated contamination index (P_c) values showed a generally low contamination or no contamination level for all soil samples in this region, followed by the order of Dali Road > Dabao Highway > Road 320 > Sixiao Highway. The same pollution source of these heavy metals was found using factor analysis.

J. Bai · B. Cui (✉) · H. Gao · Q. Ding
State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, 19 Xinjie Kou Wai Street, Beijing 100875, People's Republic of China
e-mail: cuibs@163.com

J. Bai
e-mail: junhongbai@163.com

Q. Wang
Appraisal Center of Environment and Engineering, State Environmental Protection Administration, Beijing 100012, People's Republic of China

Keywords Heavy metals · Roadside soils · Transportation period · Contamination index · Integrated contamination index

1 Introduction

Roads play a major role in stimulating social and economic progress. At present, the road number in Yunnan Province is listed as top one in China, with the road densities of 41.5 km per 100 km^2. However, road construction has also resulted in heavy environment pollution in this region (Liu et al. 2006), since road traffic is an important negative factor regarding air quality, noise and land consumption (Zechmeister et al. 2005). The contribution of cars and road transports to the global emission of atmospheric pollutants is regularly increasing (Viard et al. 2004). The road transports also induce the contamination of nearer soils by a pollutant transfer via the atmospheric fallouts (Viard et al. 2004; Nabuloa et al. 2006) or road runoff (Mitsch and Gosselink 1993; Nabuloa et al. 2006). Remarkable metal contamination, especially lead pollution, has been caused by automobile emissions in the roadside ecosystems (Garcia and Millán 1998;Von Storch et al. 2003; Sezgin et al. 2003; Nabuloa et al. 2006). The large particles of lead from vehicle emissions deposit close to the road (>90% within 1.5 m when the size >5 μm) (Hamamci et al. 1997). Nabuloa et al. (2006) reported leaves of roadside crops can accumulate trace metals at high concentrations, causing a serious health risk to consumers. Therefore, accurate measurements of the heavy metal contents in polluted soils are required to assess the potential ecological risk of these areas.

Most researchers have reported the influence of the traffic load on heavy metal contents in topsoils and their variability with distance (Ward et al. 1977; Rodriguez and Rodriguez 1982; Garcia and Millán 1998; Zhang et al. 1999; Turer and Maynard 2003). More recently, Viard et al. (2004) reported that the deposition of metals, the levels of metals in surface soils decreased with increasing distances from the highway. Moreover, he also found that the impact of the highway was clear up to 320 m, at least (lead), but the most important contamination was observed near the road. Nabuloa et al. (2006) also showed total trace metal concentrations in roadside soils decreased exponentially with increasing distance from roadways. Although the concentrations of metals in the roadside soil were influenced by meteorological conditions (Othman et al. 1997; Sezgin et al. 2003), traffic density (Garcia and Millán 1998; Nabuloa et al. 2006) and the kind of vehicle in traffic (Sezgin et al. 2003; Nabuloa et al. 2006), and soil parameters (Viard et al. 2004) were also verified in some studies, little information was known about the heavy metal accumulation in roadside soils along the roads with different transportation periods.

Therefore, the primary aim of this study are (1) to assess the heavy metal contamination of roadside topsoils along four roads with different transportation periods; (2) to corroborate the sources of the heavy metals using factor analysis.

2 Materials and methods

2.1 Site description

Four roads such as Dali Road, Road 320, Dabao Highway and Sixiao Highway were chosen in Yunnan Province, Southwest China. The four roads are located in the longitudinal range-gorge region, composed by Hengduan mountain and the adjacent mountain-valley regions on sourth-north direction. Most forestlands have been destroyed due to highway construction such as Dabao and Sixiao Highways. The road transportation period was longest for Dali Road (more than 20 years), followed by Road 320 (13 years), Dabao Highway (5 years) and Sixiao Highway (not open to traffic), because Sixiao Highway construction was just finished. The average traffic load was more than 15,000 vehicles per day (vpd) for Dali Road and Road 320, about 29,000 vpd for Dabao Highway, and 0 vpd for Sixiao Highway. The soil texture for Dali Road was loam clay soil with mean soil organic matter of 63.87 g/kg, and for other sites was loamy soil with mean soil organic matter ranging from 31.42–47.85 g/kg. Soil pH values in these sites range from 5.10 to 7.03.

2.2 Field sampling and analysis

Topsoil (0–20 cm) samples were randomly collected along the four roads from the edge of roads to the locations about 200 m off the roads in October 2005. All the roadside soil samples were air dried at room temperature and sieved through a 2-mm nylon sieve to remove coarse debris. All air-dried soil samples were then ground with a pestle and mortar until all particles passed a 100-mesh nylon sieve. Soil organic matter (SOM) was determined by the Walkley and Black (1934) method. The total heavy metal content of the prepared soil was determined after acid sequence digestion in Teflon tubes using ultrasonication. The SEPAC Method HJ/T 166-2004 (inductively coupled plasma atomic absorption spectrometry, ICP/AES) (SEPAC 2004) were used to analyze As, Cd, Cr, Cu, Ni, Pb, and Zn. A 25% of the samples were used as parallels for quality control. The results met the accuracy demand of Technical Specification for Soil Environmental Monitoring HJ/T 166-2004 (SEPAC 2004).

2.3 Statistical analysis

The significant difference between variables was assessed by the *t*-test. Factor analysis was performed to determine the sources of the heavy metals. The statistical analysis of data were performed using the software packages Origin 7.0 and SPSS 10.0 and differences considered significant if $P < 0.05$.

3 Results and discussion

3.1 Average concentrations of heavy metals in roadside soils

Concentrations of heavy metals in the topsoils along four different roads are summarized in Table 1. Concentrations are expressed in microgram per kilogram of dry weight of the soil sample. As Table 1 showed, the average concentrations of these heavy metals were obviously higher for Dali roadside soils. Generally, with the exception of As, Cu and Pb, the average concentrations of heavy metals were higher than the elemental background values in Yunnan Province. Dali Road's longest transportation period should be responsible for higher metal contents, since traffic density was similar to Road 320. The roadside soils along Sixiao Highway without traffic transportation showed lowest average levels of these heavy metals. This suggested traffic emissions led to the higher metal concentrations in soils along Dabao Highway than those in Sixiao Highway roadside soils. However, no significant difference ($P < 0.05$) was observed for the metal concentrations (except for As) in roadside soils along Road 320 and Dabao Highway. This was likely related to higher traffic density for Dabao Highway. In addition, wind and road runoff

Table 1 Statistical analysis of heavy metal concentrations in roadside topsoils along four roads

Sites		As	Cd	Cr	Cu	Ni	Pb	Zn
Dali Road ($n = 23$)	Range	4.25–52.94	0.34–2.12	94.80–233.83	30.50–93.25	49.76–136.84	37.11–74.38	65.77–134.24
	Average	14.01	0.88	142.09	44.83	78.45	51.90	102.45
	SD	13.38	0.41	43.17	19.46	24.63	10.13	17.57
Road 320 ($n = 43$)	Range	1.41–35.7	0.22–1.21	20.08–199.75	5.62–61.09	7.63–136.23	9.41–87.65	9.26–141.33
	Average	11.07	0.49	101.56	32.22	55.37	34.87	75.96
	SD	8.32	0.22	32.64	14.29	26.57	17.50	37.51
Dabao Highway ($n = 48$)	Range	1.17–14.74	0.15–1.33	48.88–181.90	2.78–67.38	13.74–96.27	11.71–74.5	9.11–136.00
	Average	5.64	0.52	105.08	31.65	54.86	33.77	84.66
	SD	3.30	0.29	36.59	17.72	19.67	19.57	36.80
Sixao Highway ($n = 18$)	Range	0.69–6.56	0.21–0.47	39.33–98.2	6.47–26.83	5.72–34.67	13.09–53.71	19.06–79.14
	Average	3.85	0.35	68.25	16.14	21.80	26.17	50.67
	SD	2.00	0.07	16.20	4.91	8.99	9.14	14.36
Elemental background values in Yunnan Province		18.4	0.218	65.2	46.3	42.5	40.6	89.7

(Sezgin et al. 2003) might be important influencing factors due to the highway located at higher altitude.

3.2 Assessment of heavy metal contamination

Assessment of soil contamination were performed by the contamination index (P_i) and integrated contamination index (P_c).

A contamination index (P_i) to describe the contamination of a given toxic substance in one region was suggested by Huang (1987) and is expressed by the fuzzy functions:

$$P_i = C_i/X_a \quad (C_i \leq X_a)$$
$$P_i = 1 + (C_i - X_a)/(X_b - X_a) \quad (X_a < C_i \leq X_b)$$
$$P_i = 2 + (C_i - X_b)/(X_c - X_b) \quad (X_b < C_i \leq X_c)$$
$$P_i = 3 + (C_i - X_c)/(X_c - X_b) \quad (C_i > X_c)$$

where C_i is the observed content of the substance; X_a is the no-polluted threshold value; X_b is the lowly polluted threshold value and X_c is the highly polluted threshold value.

Based on Chinese Environmental Quality Standard for Soils (GB 15618-1995) (SEPAC, 1995), Class I criteria was suitable to keep natural background values, and Class II could be used to the threshold values for protecting human health, while Class III could be used to the threshold values for plant growth. Therefore, X_a, X_b and X_c in above functions could be defined according to Class I, Class II and Class III criteria, respectively (Table 2).

The following terminologies are used to describe the contamination index: $P_i \leq 1$ no contamination; $1 < P_i \leq 2$ low contamination; $2 < P_i \leq 3$ moderate contamination; $P_i > 3$ high contamination.

Integrated contamination index (P_c) defined as the sum of all the minus between contamination index and one for a given region (Huang 1987). It could be calculated by the form as follows:

$$P_c = \sum_{i=1}^{7} (P_i - 1).$$

For the description of integrated contamination index the following terminologies have been used: $P_c \leq 0$ no contamination; $0 < P_c \leq 7$ low contamination; $7 < P_c \leq 21$ moderate contamination; $P_c > 2\ 1$ high contamination.

Figure 1 shows that the proportions of contamination levels in total soil samples along Dali Road, Road 320, Dabao Highway and Sixiao Highway, respectively. As pollution was not observed in all soil samples along Dabao Highway and Sixiao Highway, but about 20% of samples along Dali Road and Road 320 were lowly polluted, including 9% of highly contaminated samples along Dali Road. This was likely closely related to As accumulation due to longer transportation period.

More than 80% of soil samples were moderately or highly polluted by Cd along the four roads. Cd pollution in roadside soils followed the order of Dali Road > Dabao Highway > Road 320 > Sixiao Highway. Compared with Cd, Cr or Cu pollution was not heavier, because their low contamination or no contamination levels in more than 60% of soil samples could be observed in four sampling plots, followed by the similar order to Cd pollution. Moderate Ni contamination was observed in more than 70% of soil samples along Dali road, while more than 30% along Road 320 and Dabao Highway. All soil samples along Sixiao Highway showed neither Ni nor Cu was contaminated.

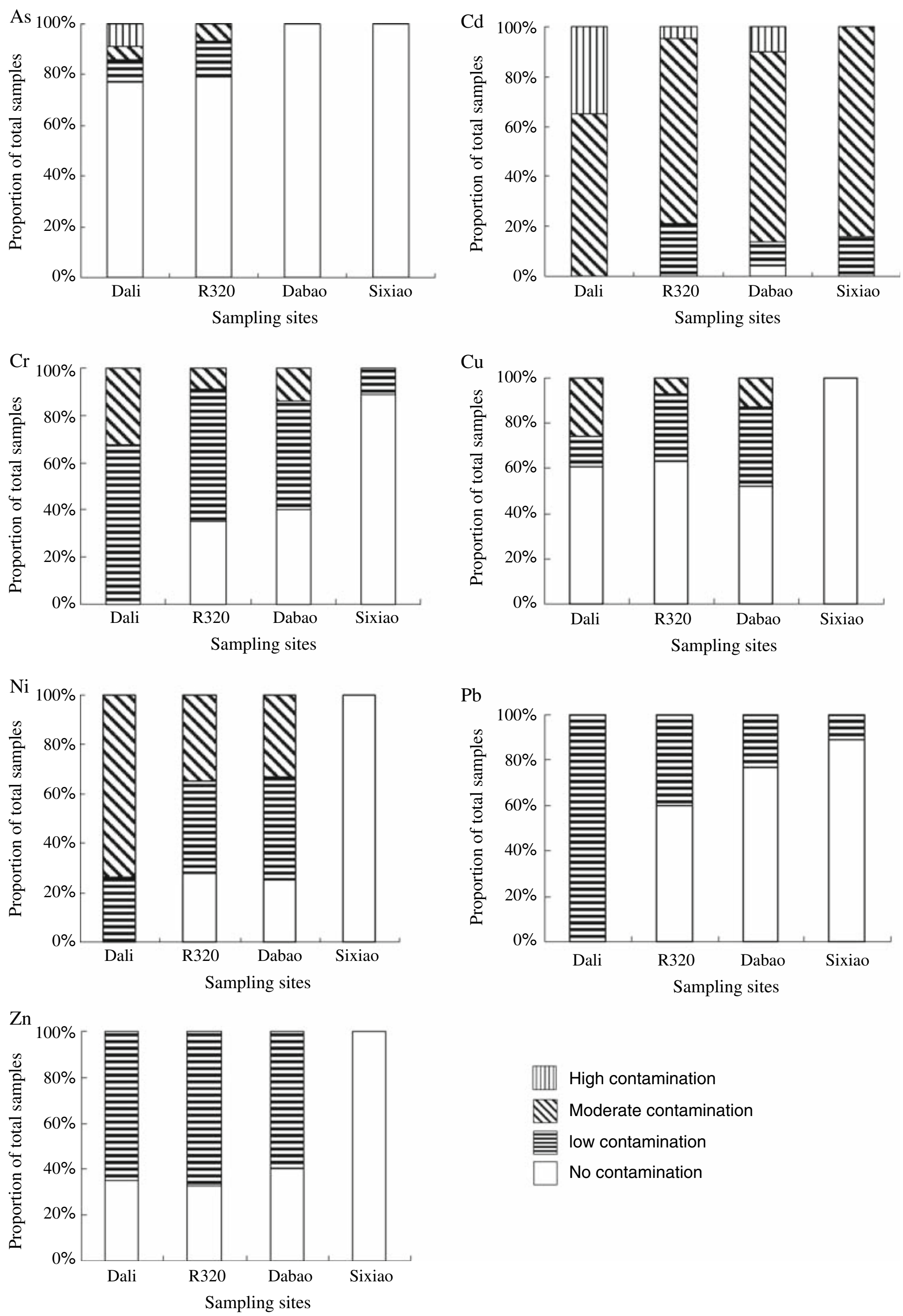

Fig. 1 Proportions of contamination levels of heavy metals in total samples

Pb pollution was low in this region since all soil samples along the four roads was lowly or no polluted, followed by the order of Dali Road > Road 320 > Dabao Highway > Sixiao Highway. High Pb adsorption capacities of plants (Bai et al. 2007) and wide use of lead free gasoline since 1990s might be the important influencing factors. Similarly, low Zn pollution was also seen from Fig. 1, and except for Sixiao Highway with no pollution, the similar proportion of soil samples with low or no Zn pollution to total roadside samples along each road could be observed.

With the exception of Zn, the heavy metal pollution was much heavier in soils along Dali Road than along the other roads. Longer transportation period should be responsibility for this, but higher contamination of these metals along Dabao Highway was likely related to higher traffic density. In only 10% of soil samples along Sixiao Highway low Cr and Pb pollution and moderate Cd pollution was observed. This was possibly related to highway construction with material transportation.

The integrated contamination indexes (P_c) are shown in Fig. 2. P_c values generally showed a low contamination or no contamination level for all soil samples along four roads in this region, followed by the order of Dali road > Dabao Highway > Road 320 > Sixiao Highway. The integrated contamination indexes exceeded zero for all the three sampling sites nearby Dali road, with a moderate contamination for the three sampling sites, suggesting that

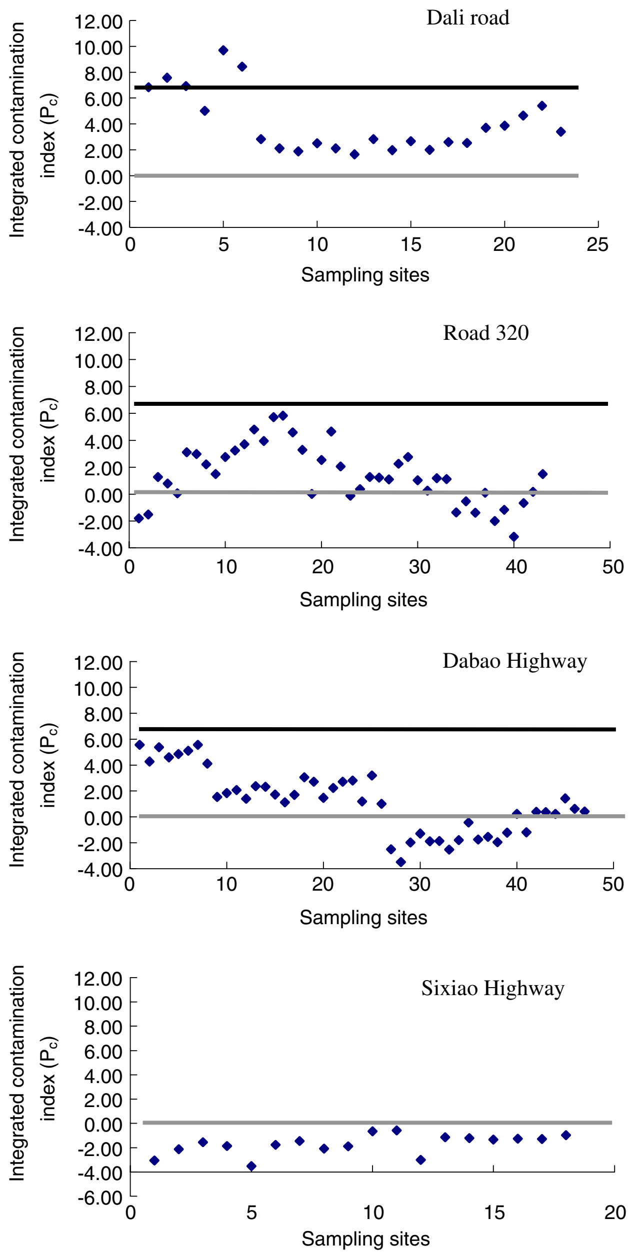

Fig. 2 Integrated contamination indexes of all soil samples from four roads. *Black* and *gray lines* are the threshold value of low pollution and no pollution, respectively

Table 2 The threshold values (X_a, X_b and X_c) for heavy metals by Chinese Environmental Quality Standard for Soils (GB 15618-1995)

	As	Cd	Cr	Cu	Ni	Pb	Zn
X_a	15	0.2	90	35	40	35	100
X_b	30	0.3	150	50	60	250	200
X_c	40	1.0	300	400	200	500	500

heavy metal pollution could reach 200 m far away from Dali road. However, all the soil samples were not polluted by heavy metals nearby Sixiao Highway. As for Road 320 and Dabao Highway, no pollution could be observed in about 60 and 30% of soil samples, respectively, and these soil samples mainly concerned these locations far away 150–200 m from roads. This could be supported by the conclusion that the most important contamination mainly occurred near the road reported by Viard et al. (2004). Therefore heavy metal concentrations in roadside soils could be obviously impacted by longer transportation period (e.g., 20 years), since soil tended to accumulate and persist metals on a relatively long-term period (Kelly et al. 1996; Garcia and Millán 1998). However, traffic density might be more important for the roads with shorter transportation period.

3.3 Factor analysis

With factor analysis is possible to get associations of heavy metals in factors that would give some information about the behavior and the source of pollution. Factor analysis was performed by evaluation of principal components and computing the eigenvectors. The rotation of principal component was carried out by the Varimax method. The results of factor analysis are shown in Table 3 for total metal contents in roadside soils along three roads except Sixiao Highway. Soil organic matter percentages were included with total metal contents in order to check their relations. Two factors described satisfactory the occurrence of metals and soil organic matter. These factors explained to a relatively large extent the total variance (65.8%) of the eight variables used in the analysis. As, Cd, Cr, Cu, Ni, Pb and Zn showed a strong association with the first factor (50.8 %), that was considered consequence of traffic pollution. Most researchers have also testified vehicle emission is one of the most important these heavy metal sources (Garcia and Millán 1998; Sezgin et al. 2003; Viard et al. 2004; Nabuloa et al. 2006), since they were included in diesel, engines, brake wear, tires, lubricating oil and galvanized parts of the vehicles (Falahi-Ardakani 1984; Zechmeister et al. 2005). The second factor, 15.03% of variance, was composed by the soil organic matter (Table 3).

Table 3 Factor analysis for heavy metal data in roadside soils along three roads except Sixiao Highway with no contamination

	F1	F2
As	0.512	
Cd	0.779	
Cr	0.708	
Cu	0.860	
Ni	0.816	
Pb	0.865	
Zn	0.734	
SOM		0.907
Variance (%)	50.811	15.029
Cumulative (%)	50.811	65.841

Factor loadings smaller than 0.5 have been removed

4 Conclusions

Heavy metal concentrations in roadside soils along the four roads confirmed the effect of the traffic as a source of pollution, although nearly all the integrated contamination indices of soil samples showed low contamination or no contamination. Factor analysis also showed traffic pollution was the responsible source for these heavy metals. Among all heavy metals, Cd and Ni pollution were obviously heavier with moderate or high contamination indices for most soils samples, but As, Pb or Zn pollution was lower along Dali Road, Road 320 and Dabao Highway. Compared with Road 320, longer transportation period should be responsible for higher heavy metal concentrations in soils along Dali Road, while higher traffic density for Dabao Highway. Heavy metal pollution could reached 200 m far away from Dali Road, while 150 m for Road 320 and Dabao Highway. In addition, low Cr and Pb pollution and moderate Cd pollution in some samples were related to highway construction along Sixiao Highway. With the increasing use of lead free petrol, the lead levels will tend to decrease continuously. Therefore, Cd or Ni should be considered as a tracer in order to assess the road transport contamination. Moreover, the method in this study is convenient and applicable, and it can be used for assessing impacts of heavy metal pollution in other similar cases across China.

Acknowledgments This work was financially supported by National Basic Research Program of China (No. 2003CB415104 and No. 2006CB403301) and the Emphasis Project Fund of National Eleven Five-Year Scientific and Technical Support Plans (No. 2006BAB04A08). We express thanks to the analysis center of Beijing Normal University. We also greatly thank two anonymous reviewers for helpful comments and English improvement.

References

Bai J, Cui B, Deng W, Wang Q, Ding Q (2007) Plant Pb contents in elevation zones of the Changbai Mountain National Nature Reserve. Pedosphere 17:229–234

Falahi-Ardakani A (1984) Contamination of environment with heavy metals emitted from automotives. Ecotoxicol Environ Saf 8:152–161

Garcia R, Millán E (1998) Assessment of Cd, Pb and Zn contamination in roadside soils and grasses from Gipuzkoa (Spain). Chemosphere 37(8):1615–1625

Hamamci C, Gumgum B, Akba O, Erdogan S (1997) Lead in urban street dust in Diyarbakir, Turkey. Fresenius Environ Bull 6:430–437

Huang R (1987) Environmental peodology. Higher Education Press, Beijing (in Chinese)

Kelly J, Thornton I, Simpson PR (1996) Urban Geochemistry: a study of influence of anthropogenic activity on heavy metal content of soils in traditionally industrial and non-industrial areas of Britain. Appl Geochem 11:363–370

Liu J., Cui B, Dong S, Zhu J, Yao W (2006) Study on the effect of highway construction on photosynthetic rate of roadsides plant in longitudinal range-Gorge Region. Chinese Sci Bull 51(Supp.):59–68

Mitsch WJ, Gosselink JG (1993) Wetlands, 2nd edn. Van Nostrand-Reinhold, USA

Nabuloa G, Oryem-Origa H, Diamond M (2006) Assessment of lead, cadmium, and zinc contamination of roadside soils, surface films, and vegetables in Kampala City, Uganda. Environ Res 101:42–52

Othman I, Al Oudat M, Al Masri MS (1997) Lead levels in roadside soils and vegetation of Damascus city. Sci Total Environ 207:43–48

Rodriguez M, Rodriguez E (1982) Lead and cadmium levels in soils and plants near highways and their correlations with traffic density. Environ Pollut Ser B4:281–290

SEPAC (State Environmental Protection Administration of China) (1995) Chinese Environmental Quality Standard for Soils (GB15618-1995) http://www.chinaep.net/hjbiaozhun/hjbz/hjbz017.htm

SEPAC (State Environmental Protection Administration of China) (2004) The technical specification for soil environmental monitoring. HJ/T 166–2004. Environmental Press of China, Beijing (in Chinese)

Sezgin N, Ozcan HK, Demir G, Nemlioglu S, Bayat C (2003) Determination of heavy metal concentrations in street dusts in Istanbul E-5 highway. Environ Int 29:979–985

Turer DG, Maynard BJ (2003) Heavy metal contamination in highway soils. Comparison of Corpus Christi, Texas and Cincinnati, Ohio shows organic matter is key to mobility. Clean Technol Environ Policy 4(4):235–245

Viard B, Pihan F, Promeyrat S, Pihan JC (2004) Integrated assessment of heavy metal (Pb, Zn, Cd) highway pollution: bioaccumulation in soil, Graminaceae and land snails. Chemosphere 55:1349–1359

Von Storch H, Costa-Cabral M, Hagner C, Feser F, Pacyna J, Pacyna E, Kolb S (2003) Four decades of gasoline lead emissions and control policies in Europe: a retrospective assessment. Sci Total Environ 311(1–3):151–176

Walkley A, Black IA (1934) An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci 38:29–37

Ward N, Brooks RR, Roberts E, Boswell CR (1977) Heavy metal pollution from automotive emissions and its effect on roadside

soils and pasture species in New Zealand. Environ Sci Technol 11:917–920
Zechmeister HG, Hohenwallner D, Hanus-Illnar A (2005) Estimation of element deposition derived from road traffic sources by using mosses. Environ Pollut 138:238–249
Zhang H, Ma D, Xie Q, Chen X (1999) An approach to studying heavy metal pollution caused by modern city development in Nanjing, China. Environ Geol 38(3):223–228